Studies on Noise measure ratio in Heterojunction Avalanche Transit Time Diode at W-band window frequency

Soumen Banerjee, Tanumoy Sarkar, Dhiman Sanyal, Pronoy Barmon, Indrajit Das

Abstract— A detailed study on the noise measure has been carried out in $Si/Si_{0.9}Ge_{0.1}$ heterojunction (p^+pnn^+ structure with $p^+ = Si_{1-x}Ge_x$, p = $Si_{1-x}Ge_x$, n = Si and n^+ = Si; mole fraction x = 0.1) and Si homojunction DDR Impatt at 94 GHz window frequency. The simulation study reveals that the noise measure for Si based Impatt is 12 times greater than that of $Si/Si_{0.9}Ge_{0.1}$ heterojunction Impatt at bias current density of 0.3×10^8 A/m^2. However the Noise Measure Ratio decays sharply with increasing current density, but still exhibits better noise performance for heterojunction IMPATT than homojunction Impatt by a factor of 1.75 at bias current density of 2×10^8 A/m^2.The result also shows that the noise measure decreases with increasing value of negative resistance of the device.

Index Terms— Double Drift IMPATT diode, Homojunction and Heterojunction Impatt, Noise Measure Ratio, Silicon-Germanium, W-band

1 Introduction

THE W-Band (75-110 GHz) is of relative importance at the window frequency of 94 GHz owing to relatively low atmospheric attenuation. It also opens application windows in fields of communication and commercial satellites, high resolution close range targeting radar, millimeter wave radar research and applications in astronomy, defence, some non-military and security applications [1]. IMPATT (IMpact Avalanche Transit Time) covers a wide range of frequency spectrum starting from X-Band to submillimeter wave region. It has emerged as a powerful solid state source delivering high output power.

Impatt based on conventional materials like Si, Ge, GaAs, etc are very popular owing to their easy fabrication methodology, low manufacturing cost and accounts for a lot of sales in the global semiconductor market. Yet the driving force behind today's growth in high speed optical networking and inexpensive, light weight personal communication devices is definitely Silicon-Germanium (SiGe). The technology based on SiGe enables the design of more functional components on a chip leading to its popularity as the perfect material of choice for both wireless integrated circuits and low power RF chips. The SiGe technology incorporates the augmentation of the electrical properties of Si with Ge to make the chips operate more efficiently thereby bridging between low cost, low power, low frequency Si chips with that of high cost, high power, high frequency chips made of GaAs and InP. SiGe provides the flexibility to the IC manufacturers to reengineer the band gap of Si for better performance resulting in a heterojunction system compatible with Si technology. $Si_{1-x}Ge_x$ layers on Si has been developed for fabrication of Heterojunction Bipolar Transistors (HBTs), Modulation Doped Field Effect Transistors (MODFETs), Bipolar Complementary MOS (BiCMOS) and IR photoconductors that operate in millimeter wave domain making $Si_{1-x}Ge_x$ a viable material for millimeter wave source and related circuit applications [2],[3],[4],[5],[6]. Heterostructure IMPATT and MITATT (Mixed Ionization Tunneling and Avalanche Transit Time) diodes have been reported in recent literature [7],[8],[9],[10],[11]. From literature the ionization rate of holes in SiGe is higher than the ionization rate of electrons. The potential application of $Si/Si_{0.9}Ge_{0.1}$ based Impatt has aroused great interest among the authors to study the effect of Noise Measure Ratio in $Si/Si_{0.9}Ge_{0.1}$ heterojunction Impatt and Si homojunction Impatt.

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2 Design Procedure and Method of Simulation

The flat profile p^+pnn^+ $Si/Si_{0.9}Ge_{0.1}$ heterojunction DDR IMPATT under consideration has both p and p^+ layers of $Si_{0.9}Ge_{0.1}$ with mole fraction x=0.1 and both n and n^+ layers of Si. The schematic structure, doping profile and electric field profile of heterojunction DDR IMPATT are shown in Fig. 1. The ionization rate data are taken from [12], carrier saturation drift velocities are evaluated by the full-band model in the undoped $Si_{1-x}Ge_x$ as a function of Ge content from [13] and the other material parameters for SiGe and Si are taken from data reported elsewhere [14],[15],[16]. A computer simulation method based on drift division model and available for Si based homojunction Impatt [16],[17],[18] is modified for $Si/Si_{1-x}Ge_x$ heterojunction DDR Impatt. The DC bias current density is varied from 0.3×10^8 A/m^2 to 2×10^8 A/m^2 and both DC and small signal parameters all obtained both for $Si/Si_{1-x}Ge_x$ heterojunction and Si homojunction Impatt. The noise measure for both the devices are studied from the definition [19], [20] as

$$M=(\langle v^2\rangle/df)/4kT(-R) \quad (1)$$

$\langle v^2\rangle/df$ is the mean square noise voltage per bandwidth (noise spectral density) which can be computed from the following equation given below:

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$$\langle v^2\rangle/df=(2q/J_0.A).(1+W/x_A)^2/\alpha'^2 \quad (2)$$

W and x are the depletion and avalanche region width respectively. J_0 is the DC current density, A is the real area of the diode, K is the Boltzmann constant, T is temperature in Kelvin, (-R) is the real part of the device impedance.

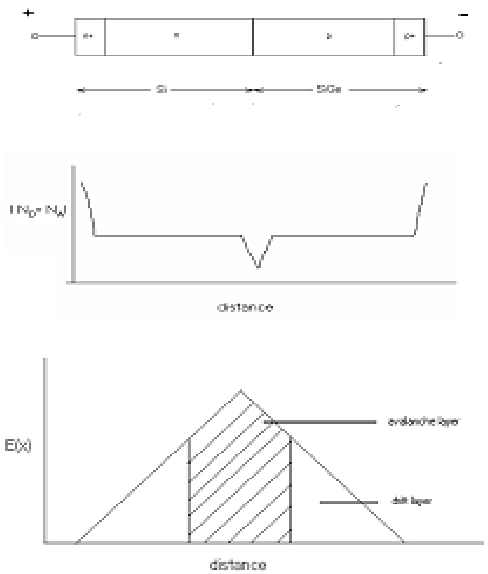

Fig. 1. Structure of Si/$Si_{1-x}Ge_x$ heterojunction DDR Impatt diode and its doping profile and Electric Field Profile

3 Results and Discussions

The material parameters of both silicon and silicon-germanium are enlisted in Table 1. The various DC and small signal properties of Si/$Si_{0.9}Ge_{0.1}$ heterojunction and Si homojunction DDR Impatt needed to study the noise measure ratio is shown in Table 2. The space charge limited performance of the homojunction and heterojunction DDR impatt is also revealed through data in Table 2. The results clearly show that if the bias current density increases by same proportion for both heterojunction and homojunction impatt, the percentage increase of x_A/w is more appreciable for heterojunction impatt leading to the conclusion that the space charge limitation performance is more pronounced for heterojunction impatt that for its homojunction counterpart. The avalanche noise is also reduced when the difference between the ionization coefficients is large. Table 2 also reflects the noise measure ratio of the diodes. The authors have not calculated the actual value for noise measure, instead the ratio of noise measures for two different structures have been studied. Fig. 2 depicts a plot of noise measure ratio vs input current density. A close inspection of the figure reveals that the noise margin for Si homojunction diode is 12 times greater than that of the heterojunction Impatt, but the ratio falls very sharply with increasing current density. It is observed that the noise performance of heterojunction Impatt is better in comparison to the homojunction by a factor of 1.75 near $J_0=2\times10^8$A/m². This result is consistent with the observation that the heterojunction impatt performance degrades at lower current density in comparison to its homojunction counterpart. It also reveals that the noise measure decreases with increasing values of negative resistance of the device. The results are very helpful for designing low noise Impatts based on Si/$Si_{0.9}Ge_{0.1}$.

TABLE 1
Material Parameters of Silicon and Silicon-Germanium

Parameters	Silicon	$Si_{1-x}Ge_x$
A_n (10^8m^{-1})	0.62	3.65
b_n (10^8Vm^{-1})	1.08	0.99
A_p (10^8m^{-1})	2.00	6.44
b_p (10^8 Vm^{-1})	1.97	1.57
Ah_n (10^8m^{-1})	0.50	3.65
bh_n (10^8V m^{-1})	0.99	0.99
Ah_p (10^8 m^{-1})	0.56	6.44
bh_p (10^8V m^{-1})	1.32	1.57
v_{sp} (10^5ms^{-1})	0.76	0.70
v_{sp} (10^5ms^{-1})	1.00	0.72
μ_n (m^2 V^{-1}s^{-1})	0.135	0.055
μ_p (m^2 V^{-1}s^{-1})	0.048	0.051
ε (10^{-09} Fm^{-1})	0.104	0.109

A_n, A_p, b_n, b_p : Ionization coefficient of electrons and holes resp. at low fields
Ah_n, Ah_p, bh_n, bh_p : Ionization coefficient of electrons and holes resp. at high fields
v_{sn},v_{sp} : Saturation drift velocity of electrons and holes respectively
μ_n ,μ_p : Mobility of electrons and holes respectively

TABLE 2
Data for comparison of Noise Measure Ratio between Si and Si/SiGe Impatts

Input current density (10^8A/m^2)		0.3	0.5	0.7	1.0	2.0
Depletion width w (10^{-6} m)	Si/$Si_{1-x}Ge_x$	0.898	0.898	0.898	0.898	0.898
	Si	0.898	0.898	0.898	0.898	0.898
Avalanche width x_A (10^{-6} m)	Si/$Si_{1-x}Ge_x$	0.298	0.316	0.32	0.33	0.38
	Si	0.412	0.416	0.424	0.429	0.458
$\alpha^1=\delta\alpha/\Delta e$ at $E=E_m$. (m/v-s)	Si/$Si_{1-x}Ge_x$	0.5063	0.5038	0.4938	0.4919	0.4559
	Si	0.30534	0.30502	0.30482	0.30454	0.30342
Negative Resistance $-Z_R$ (10^{-8} Ωm^2)	Si/$Si_{1-x}Ge_x$	4.4094	4.7073	2.3206	1.83648	0.79958
	Si	0.8004	1.9438	1.4098	1.3107	0.90729
Ratio of Noise Measure		12	5.431	3.537	3.038	1.751

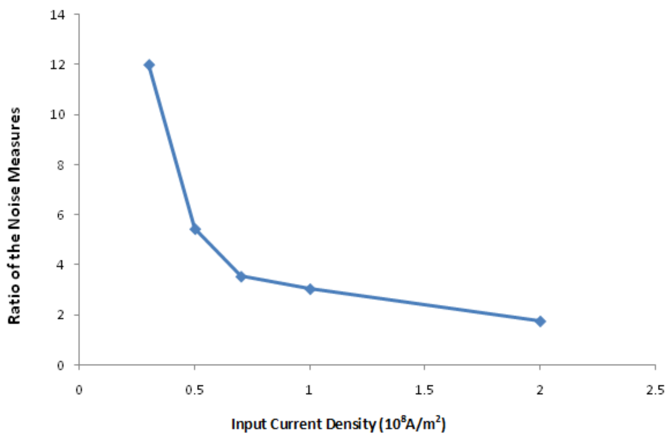

Fig. 2. Noise Measure Ratio vs Input Current Density Plot at 94 GHz

4 Conclusion

The simulation results reveal that the design and performance of Impatt diode using a totally new material $Si/Si_{1-x}Ge_x$ is very impressive and suggest that $Si/Si_{1-x}Ge_x$ should be fabricated and used as a low noise millimeter wave source generating high power with greater efficiency. Thus $Si/Si_{1-x}Ge_x$ based Impatts will play an important role in the millimeter wave communication system and Radar system in very near future.

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